K-shell Emission of Neutral Iron Line from Sgr B2 Excited by Subrelativistic Protons.

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Abstract

We investigated the emission of Kα iron line from the massive molecular clouds in the Galactic center (GC). We assume that at present the total flux of this emission consists of time variable component generated by primary X-ray photons ejected by Sagittarius A* (Sgr A*) in the past and a relatively weak quasi-stationary component excited by impact of protons which were generated by star accretion onto the central black hole. The level of background emission was estimated from a rise of the 6.4 keV line intensity in the direction of several molecular clouds, that we interpreted as a stage when the X-ray front ejected by Sgr A* entered into these clouds. The 6.4 keV emission before this intensity jump we interpreted as emission generated by subrelativistic cosmic rays there. The cross-section of Kα vacancies produced by protons differs from that of electrons or X-rays. Therefore, we expect that this processes can be distinguished from the analysis of the equivalent width of the iron line and time variations of the width can be predicted. The line intensity from the clouds depends on their distance from Sgr A* and the coefficient of spacial diffusion near the Galactic center. We expect that in a few years the line intensity for the cloud G 0.11−0.11 which is relatively close to Sgr A* will decreases to the level $\lesssim 10\%$ from its present value. For the cloud Sagittarius B2 (Sgr B2) the situation is more intricate. If the diffusion coefficient $D \gtrsim 10^{27}$ cm^2 s^{-1} then the expected stationary flux should be about 10% of its level in 2000. In the opposite case the line intensity from Sgr B2 should drop down to zero because the protons do not reach the cloud.

Key words: Galaxy: center — X-rays: ISM – ISM: clouds — cosmic rays

1. Introduction

The bright iron fluorescent Kα line in the direction of the molecular clouds in the Galactic center (GC) region was predicted (Sunyaev et al. 1993) and then discovered (Koyama et al. 1996) more than twenty years ago. It was assumed that this flux arose due to the K-absorption of keV photons by dense molecular clouds irradiated by external X-rays, possibly from the super-massive black hole, Sagittarius A* (Sgr A*), which was active in the recent past, (300 – 400 years ago (Sunyaev et al. 1993; Koyama et al. 1996)), but is almost unseen at present (see e.g. Baganoff et al. 2003 and Porquet et al. 2003). Recent observations found a steady decrease of the X-ray flux from Sagittarius B2 (Sgr B2) (Koyama et al. 2008; Inui et al. 2009; Terrier et al. 2010; Nobukawa et al. 2011). This is a strong evidence that the origin of the variable component is, indeed, a reflection of the primary X-ray flare.

The duration of Sgr A* activity is uncertain. Thus, Murakami et al. (2003) obtained the luminosity history of the galactic nuclei Sgr A* during the last 500 years. They concluded that Sgr A* was as luminous as $F_{fl} \sim 10^{39}$ erg s^{-1} a few hundred years ago, and has dimmed gradually since then. Revnivtsev et al. (2004) found no significant variability of the line flux from Sgr B2 during the period 1993-2001. The constancy of the line flux meant that the luminosity of Sgr A* remained approximately constant for more than 10 years a few hundred years ago. Inui et al. (2009) confirmed this variability of Sgr A* activity with a time scale $\sim$10 years. And, finally Ponti et al. (2010) concluded that this activity might have started a few hundreds of years ago and lasted until about 70 – 150 years ago.

An appropriate duration of Sgr A* X-ray activity can be caused by shocks resulting from interaction of jets with the dense interstellar medium (Yu et al. 2010).

Kα emission from the clouds can be generated by subrelativistic electrons with energies above 7 keV. This model was proposed by Yusef-Zadeh et al. (2002) (see also Yusef-Zadeh et al. 2007a; Yusef-Zadeh et al. 2007b) who assumed that a correlation between the nonthermal radio filaments and the X-ray features when combined with the distribution of molecular gas might suggested that the impact of the subrelativistic electrons with energies 10–100 keV from local sources with diffuse neutral gas produced both bremsstrahlung X-ray continuum and diffuse 6.4 keV line emission. The excess of supernova remnants detected in the GC region was supposed to be responsible for enhancing the flux of subrelativistic electrons. The characteristic time of Kα emission in this case is about ≥ 1000 years, i.e. about the lifetime of subrelativistic electrons (for the rate of electron energy losses see e.g. Hayakawa 1969). The total energy release of a supernova is about 10^{51} erg.

Observations indicated on even more energetic phenomena which might occur in the GC. Thus, a hot plasma with the temperature about 10 keV was found in the GC which can be heated if there are sources with a power $\sim 10^{41}$ erg s^{-1} (see e.g. Koyama et al. 1996), which could be generated by events of huge energy release in the past. It was shown that

the energy about 10^{53} erg can be released if the central black hole captured a star (see e.g. Alexander 2005; Cheng et al. 2006; Cheng et al. 2007). As a result, a flux of subrelativistic protons is ejected from the GC, which heats the central region (Dogiel et al. 2009b). These protons can also produce 6.4 keV line emission from molecular clouds (Dogiel et al. 2009a), which is, however, stationary because the lifetime of these protons $\tau_p \sim 10^7$ yr (Dogiel et al. 2009c) is much longer than the characteristic time of star capture by the central black hole ($\tau_c \sim 10^5$ yr) (Alexander 2005). This scenario assumed at least two components of the X-ray line and continuum emission from the clouds: the first is a time variable component generated by X-rays from sources in the GC, and the second is a quasi-stationary component produced by subrelativistic protons interacting with the gas.

The question whether the X-ray emission from the central region (within $\leq 0^\circ\!.3$ radius) is really diffuse was analysed in Koyama et al. (2007b) who showed that the hot plasma distribution in the GC, traced by the 6.7 keV iron line emission, did not correlate with that of point sources whose distribution was derived from IR observations that differed from the other disk where the correlation was quite good. Recently, Revnivtsev et al. (2009) showed from the Chandra data that most ($\sim 88\%$) of the ridge emission is clearly explained by dim and numerous point sources. Therefore, at least in the ridge emission, accreting white dwarfs and active coronal binaries are considered to be main emitters. We notice however that Revnivtsev et al. 2009 observed regions in the disk located at $1^\circ\!.5$ away from the GC.

Observations of the 6.4 keV flux from Sgr B2 have not found up to now any reliable evident stationary component though as predicted by Ponti et al. (2010) a fast decrease of 6.4 keV emission observed with XMM-Newton for several molecular clouds suggested that the emission generated by low energy cosmic rays, if present, might become dominant in several years. Nevertheless, for several clouds, including Sgr B, observations show temporary variations of 6.4 keV emission both rise and decay of intensity (see Inui et al. 2009; Ponti et al. 2010). We interpreted this rise of emission as a stage when the X-ray front ejected by Sgr A* entered into these clouds and the level of background generated by cosmic rays as the 6.4 keV emission before the intensity jump.

Below we shall show that if this stationary component exists it can be predicted from time variations of the line emission from the clouds.

2. Equivalent Width of the 6.4 keV Line

In the framework of the reflection model, primary X-rays from an external source produce fluxes of continuum and line emission from irradiated molecular clouds. In principle, the surface brightness distribution, the equivalent width and the shape of the fluorescent line depend on the geometry of the source-reflector-observer (see Sunyaev & Churazov 1998) but for rough estimates we can neglect this effect. The continuum flux from the clouds is proportional roughly to

$$F_X \propto n_H \sigma_T c N_X\,, \tag{1}$$

where n_H if the hydrogen density in the cloud, σ_T is the Thomson cross-section, and N_X is the total number of primary photons with the energy of a produced X-ray $E_X \sim 7.1$ keV inside the cloud.

The flux of 6.4 keV line is

$$F_{6.4} \propto n_H \sigma_{6.4}^X c \eta N_X\,, \tag{2}$$

where η is the iron abundance in the cloud and $\sigma_{6.4}^X$ is the cross-section of the line production by the primary X-ray flux. Then the equivalent width (eW) of the line in the framework of the reflection model is

$$eW = \frac{F_{6.4}^X}{F_X(E_X = 6.4\ keV)} \propto \frac{\sigma_{6.4}^X \eta}{\sigma_T} = f(\eta)\,. \tag{3}$$

The intensity of the Fe Kα line excited by subrelativistic particles (electrons or protons) in a cloud can be calculated from

$$F_{K_\alpha} = 4\pi\eta\omega_K \int\limits_r n_H(r) r^2 dr \int\limits_E v(E)\sigma_K \tilde{N}(E,r) dE\,, \tag{4}$$

where v and E are the velocity and the kinetic energy of subrelativistic particles, σ_K is the cross-section for 6.4 keV line production by subrelativistic particles,

$$\sigma_K = \sigma_Z^I \eta \omega_Z^{KI}\,. \tag{5}$$

Here σ_Z^I is the cross section for the K-shell ionization of atom Z by a charged particle of energy E (see Garcia et al. 1973; Quarles 1976), ω_Z^{KI} is the Ki fluorescence yield for an atom Z.

The flux of bremsstrahlung radiation is

$$\Phi_x = 4\pi \int\limits_0^\infty n_H(r) r^2 dr \int\limits_E dE \tilde{N}(E,x,t) \frac{d\sigma_{br}}{dE_x} v(E)\,. \tag{6}$$

Here $d\sigma_{br}/dE_x$ is the cross section of bremsstrahlung radiation (see Hayakawa 1969)

$$\frac{d\sigma_{br}}{dE_x} = \frac{8}{3} Z^2 \frac{e^2}{\hbar c} \left(\frac{e^2}{mc^2}\right)^2 \frac{mc^2}{E'} \frac{1}{E_x} \ln \frac{\left(\sqrt{E'} + \sqrt{E' - E_x}\right)^2}{E_x}\,, \tag{7}$$

where $E' = E_e$ for electrons and $E' = E_p = (m_p/m_e)E_e$ for protons. One can find also all these cross-sections in Tatischeff (2003).

In principle the particle and X-ray scenarios can be distinguished from each other from characteristics of emission from the clouds because the cross-sections for collisional and photoionization mechanisms are quite different. If the photoionization cross-sections are steep functions of energy (they vary approximately as E_X^{-3} from ionization thresholds), the cross sections for collisional ionization have a much harder energy dependence. Therefore, while fluorescence is essentially produced by photons with energy contained in a narrow range of a few keV above the ionization threshold, subrelativistic particles can produce significant X-ray line

emission in an extended energy range above the threshold (Tatischeff 2003). The continuum emission in these two models is also generated different processes : by the bremsstrahlung in the collisional scenario and by the Thomson scattering in the photoionization scenario.

The cross-sections of bremsstrahlung and Kα production by subrelativistic protons and electrons are shown in figure 1. As one can see from the figure the cross-section of the proton

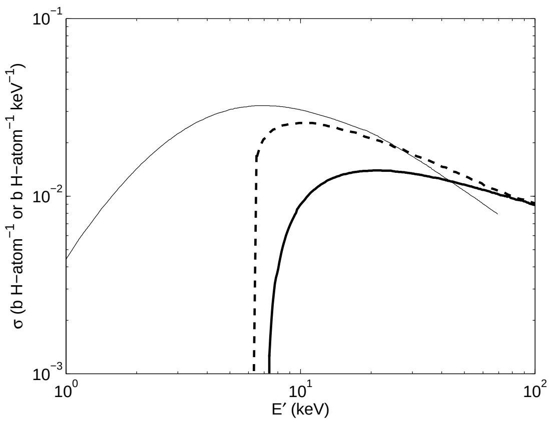

Fig. 1. Cross section of electron and proton bremsstrahlung radiation at the energy 6.4 keV, $d\sigma_{br}/dE_x$ (dashed line), and the cross-sections σ_K of Kα production for electron (thick solid line) and proton (thin solid line). Here $E' = E_e$ for electrons and $E' = (m_e/m_p)E_p$ for protons. Here ω_K equals 0.3 and η is taken to be twice solar.The data for this figure was kindly sent to us by Vincent Tatischeff.

bremsstrahlung with the energy $E_p = (m_p/m_e)E_e$ is completely the same as for electrons with the energy E_e and for protons , as shown in figure 1 by the dashed line. However the cross-sections σ_K of Kα lines produced by electrons (thick solid line) and by protons (thin solid line) are quite different. If for electrons the cross-section σ_K of the iron line has a sharp cut-off at $E = 7.1$ keV, that for protons is rather smooth, and a contribution from protons with relatively small energies can be significant.

The photoionization and collisional scenarios can be distinguished from the equivalent width of iron line. The eW depends on the chemical abundance in the GC, which is poorly known for the GC. Direct estimations of the iron abundance there provided by the Suzaku group (Koyama et al. 2007b; Koyama et al. 2009) gave the value from 1 to 3.5 solar. Revnivtsev et al. (2004) got the iron abundance for the cloud Sgr B2 at about 1.9 solar. Nobukawa et al. (2010) found that the equivalent width of line emission from a cloud near Sgr A requires the abundance higher than solar. For the line emission due to impact of subrelativistic electrons, the iron abundance in Sgr B2 should be about 4 solar, while the X-ray scenario requires ~ 1.6 solar. Therefore, Nobukawa et al. (2010) concluded that the irradiating model seemed to be more attractive than the electron impact scenario. This abundance is compatible with the value $\eta = 1.3$ solar estimated by Nobukawa et al. (2011) from the iron absorption edge at 7.1 keV.

The eW for the case of particle impact depends on their spectrum. Its value for power-

law spectra of particles ($N \propto E^{\gamma}$) is a function of the spectral index γ and the abundance η:

$$eW = \eta\omega_K \frac{\int\limits_E v(E)\sigma_K(E)E^{\gamma}dE}{\int\limits_E E^{\gamma}(d\sigma_{br}(\bar{E},E)/dE_x)v(E)\ dE} = f(\eta,\gamma)\,. \tag{8}$$

For the solar iron abundance the eW for electrons and protons is shown in figure 2. It was assumed here that the proton spectrum has a cut-off ($N = 0$ at $E > E_{inj}$, see below).

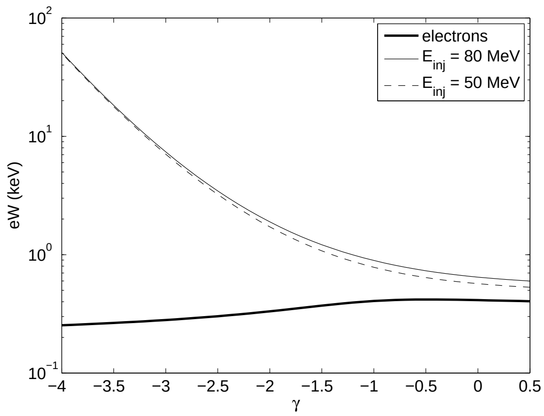

Fig. 2. Equivalent width of Kα line for the solar abundance produced by electrons (thick solid line) and protons (thin solid line for injection energy $E_{inj} = 80$ MeV, dashed line for injection energy $E_{inj} = 50$ MeV) as a function of the spectral index γ.

One can see that the equivalent width of Kα line generated by electrons depends weakly on γ, and it varies from ~ 250 eV for soft spectra to ~ 500 eV for hard electron spectra (see also in this respect Yusef-Zadeh et al. 2007a). In the case of protons the width variations are significant reaching its maximum for very soft proton spectra. As one can see from this figure the equivalent width weakly depends on the maximum energy of protons, E_{inj}.

Sources of high energy particles in the Galaxy generate quite wide range of characteristics of their spectra, though the most effective process in the cosmic space, acceleration by shocks, provide particle spectra with the spectral index γ close to -2. For the case of accretion we approximated the spectrum of proton injection by the delta-function distribution which was modified then by Coulomb losses into a power-law spectrum with $\gamma = 0.5$ (see Dogiel et al. 2009c). We notice, however, that this delta-function approximation is a simplification of the injection process. As it was shown by Ginzburg et al. (2004) for jets, at first stages of evolution the jet material moves by inertia. Then because of excitation of plasma instabilities in the flux, the particle distribution functions, which were initially delta functions both in angle and in energy, transform into complex angular and energy dependencies.

Below we present briefly parameters of the proton spectrum for the case of a star capture by a massive black hole (for details see Dogiel et al. 2009a; Dogiel et al. 2009c).

3. Model of Proton Injection in the GC

We mention first of all that penetration of subrelativistic protons into molecular clouds is supposed to be a rather natural process in the Galaxy. Thus, investigations showed that heating and ionization of Galactic molecular clouds can be produced by subrelativistic protons penetrating there (see e.g. Dalgarno & McCray 1972; Spitzer & Jenkins 1975; Nath & Biermann 1994; Dogiel et al. 2009a; Crocker et al. 2010). If so, one expect also a flux of the 6.4 keV line and continuum emission from these clouds generated by these protons.

In the GC subrelativistic protons can be generated by processes of star accretion on the super-massive black hole. Once passing the pericenter, the star is tidally disrupted into a very long and dilute gas stream. The outcome of tidal disruption is that some energy is extracted out of the orbit to unbind the star and accelerate the debris. Initially about 50% of the stellar mass becomes tightly bound to the black hole, while the remainder 50% of the stellar mass is forcefully ejected (Ayal et al. 2000). Then the total number of subrelativistic protons produced in each capture of one solar mass star is $N_k \simeq 10^{57}$.

The kinetic energy carried by the ejected debris is a function of the penetration parameter $b^{-1} = r_t/r_p$, where r_p is the periapse distance (distance of closest approach) and r_t is the tidal radius. This energy can significantly exceed that released by a normal supernova ($\sim 10^{51}$ erg) if the orbit is highly penetrating (Alexander 2005),

$$W \sim 4 \times 10^{52} \left(\frac{M_*}{M_\odot}\right)^2 \left(\frac{R_*}{R_\odot}\right)^{-1} \left(\frac{M_{\rm bh}/M_*}{10^6}\right)^{1/3} \left(\frac{b}{0.1}\right)^{-2} \text{erg}\,. \tag{9}$$

where M_* and R_* is the mass and the radius of the captured star, and $M_{\rm bh}$ is the mass of black hole.

For the star capture time $\tau_s \sim 10^4 - 10^5$ years (Alexander 2005) it gives a power input $W \sim 10^{41}$ erg s^{-1}. The mean kinetic energy per escaping nucleon is given by

$$E_{\rm inj} \sim 42 \left(\frac{\eta}{0.5}\right)^{-1} \left(\frac{M_*}{M_\odot}\right) \left(\frac{R_*}{R_\odot}\right)^{-1} \left(\frac{M_{\rm bh}/M_*}{10^6}\right)^{1/3} \left(\frac{b}{0.1}\right)^{-2} \text{MeV}\,, \tag{10}$$

where ηM_* is the mass of escaping material. For the black-hole mass $M_{\rm bh} = 4.31 \times 10^6\ M_\odot$ the energy of escaping particles is

$$E_{\rm inj} \sim 68(\eta/0.5)^{-1}(b/0.1)^{-2}\ \text{MeV nucleon}^{-1} \tag{11}$$

when a one-solar mass star is captured.

Subrelativistic protons lose their energy by collision with background particles and the lifetime of subrelativistic protons in the GC with energies $E \leq 100$ MeV is of the order of

$$\tau_p \sim \sqrt{\frac{E_p^3}{2m_p}} \frac{m_e}{3\pi n e^4 \ln\Lambda} \sim 10^7 \text{ years} \tag{12}$$

where $n \sim 0.1$ cm^{-3} is the plasma density in the GC, e and m are the electron charge and its rest mass, respectively, and $ln\Lambda$ is the Coulomb logarithm. Because $\tau_s \ll \tau_p$, then the proton

injection can be considered as quasi-stationary.

The spatial and energy distribution of these protons in the central GC region can be calculated from the equation

$$\frac{\partial N}{\partial t} - \nabla\left(D\nabla N\right) + \frac{\partial}{\partial E}\left(\frac{dE}{dt}N\right) = Q(E,t)\,, \tag{13}$$

where dE/dt is the rate of Coulomb energy losses, D is the spatial diffusion coefficient in the intercloud medium and the rhs term Q describes the process proton injection in the GC

$$Q(E,\mathbf{r},t) = \sum_{k=0} N_k \delta(E - E_{inj})\delta(t - t_k)\delta(\mathbf{r})\,, \tag{14}$$

where N_k is the number of injected protons and $t_k = k \times T$ is the injection time.

The proton distribution inside molecular clouds is described by similar equation but with a different diffusion coefficient and rates of energy losses

$$\frac{\partial}{\partial E}\left(b_c(E)\tilde{N}\right) - D_c\frac{\partial^2}{\partial x^2}\tilde{N} = 0\,, \tag{15}$$

with the boundary conditions

$$\tilde{N}|_{x=0} = N_c, \qquad\qquad \tilde{N}_p|_{x=\infty} = 0\,. \tag{16}$$

where N_c, the proton density at the cloud surface, is calculated with equation (13), D_c and b_c are the diffusion coefficient and the rate of energy losses inside the cloud. The value of D_c for the clouds is uncertain though there are theoretical estimates of this value provided by Dogiel et al. (1987) who gave the value $\sim 10^{24} - 10^{25}$ cm^2 s^{-1}. For details of calculations see Dogiel et al. (2009a).

4. Stationary and Time-Variable Components of X-Ray Emission from the GC Molecular Clouds

The following analysis is based on the cloud observations by XMM-Newton obtained by Ponti et al. (2010). These clouds showed different time variations of the line emission which were interpreted by the authors in terms of the reflection model. The distances of the clouds from Sgr A* was chosen in that way to explain the observed variations of the line emission for each of these clouds. Several clouds of the Bridge complex show a rather low flux before a sudden jump of the 6.4 keV intensity in about one order of magnitude that was interpreted as a result of the X-front radiation which just had reached these clouds (see figure 5, 6, and 11 in Ponti et al. 2010). Basing on these observations we make the two key assumptions:

1. The low level of 6.4 keV intensity from the clouds before the jump represents a stationary component of the emission from the clouds. This assumption does not seem to be incredible. Suzaku observations show also faint 6.4 keV emission from the GC region which is more or less uniformly distributed there (see Koyama et al. 2009). We cannot exclude that this extended diffuse emission may also represent a stationary line component.

2. This emission from the clouds before the jump is generated by proton impact.

For our analysis we used also parameters of the two other clouds which showed time variations of the 6.4 keV emission. With some modeling of proton penetration into the clouds described in the previous section we can calculate stationary components of continuum and the 6.4 keV line emission from the clouds produced by protons. The diffusion coefficient D in the GC is unknown and therefore is a free parameter of the problem. For calculations we took parameters for the three clouds which are listed in Ponti et al. (2010):

- Bridge, the density $n_H = 1.9 \cdot 10^4$ cm^{-3}, the radius of the cloud $r = 1.6$ pc, the distance from Sgr A* $R = 63$ pc;
- the same for the cloud G 0.11−0.11, $n_H = 1.8 \cdot 10^3$ cm^{-3}, $r = 3.7$ pc, $R = 30$ pc;
- the same for Sgr B2, $n_H = 3.8 \cdot 10^4$ cm^{-3}, $r = 7$ pc, $R = 164$ pc.

Intensity of the 6.4 keV line produced by photoionization depends on the number of primary photons penetrating into a cloud. The density of primary X-ray flux from Sgr A* decreases with the distance R as: $\propto R^{-2}$. Then with the known parameters of X-ray and proton production by Sgr A* we can calculate for each of these clouds, the ratio of the stationary component of the 6.4 keV line produced by the protons, $F^p_{6.4}$, to the time variable component at its peak value from irradiation by primary X-rays, $F^X_{6.4}$. To do this we use the observed ratio $F^p_{6.4}/F^X_{6.4} = 0.1$ for the Bridge as it follows from the XMM-Newton data (Ponti et al. 2010). For the clouds G0.11−0.11 and Sgr B2 this ratio as a function of the diffusion coefficient D is shown in figure 3.

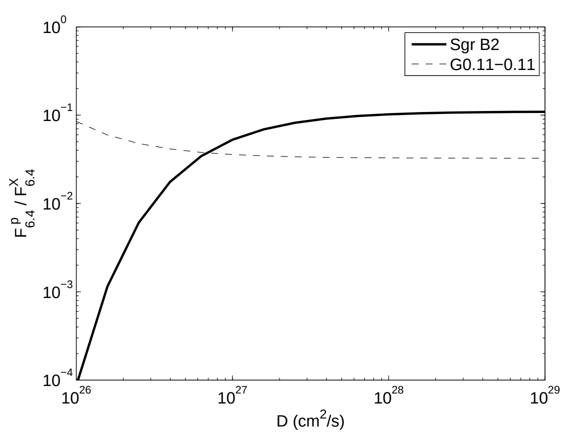

Fig. 3. The ratio $F^p_{6.4}/F^X_{6.4}$ for the cloud G 0.11−0.11 and Sgr B2 as a function of the diffusion coefficient D

One can see that protons can contribute to the total 6.4 keV flux from Sgr B2 if the diffusion is large enough, $D \gtrsim 10^{27}$ cm^2 s^{-1}. Then the expected stationary flux should be one order of magnitude less than the observed 6.4 keV emission from Sgr B2 near its maximum in 2000. For small values of D there is no chance to observe 6.4 keV emission from Sgr B2 when

the X-ray front has crossed the cloud. For the cloud G 0.11−0.11 which according to Ponti et al. (2010) is relatively close to Sgr A* the situation is different. The intensity of stationary component is quite high almost independently of D and, in principle, may be detected in several years.

Ponti et al. (2010) estimated the front width of primary X-rays from a non-detection of 6.4 keV emission from the two molecular (the 20 and 50 km s^{-1} clouds) with a mass more than $10^4 M_\odot$ (Tsuboi et al. 1999) which are within 15 pc of Sgr A*. Ponti et al. (2010) assumed the X-ray front had passed already these clouds which were very close to Sgr A* and, therefore, they do not shine anymore. From figure 3 it follows that in this case a stationary 6.4 keV component should be seen after the front passage. We notice that the distances to the clouds was estimated from the assumption that the envelopes of nearby SN remnants interact with these clouds Coil & Ho (2000). If this is true then it is very surprising that fluxes of continuum and line emission are not observed from these clouds at all (as expected in the model of Yusef-Zadeh et al. 2002). As follows from Bykov et al. (2000) when a shock front of SN interacts with a molecular cloud, energetic electrons generated at the shock produces an intensive flux of hard X-rays from the cloud. So, it is very strange that in such a situation X-ray emission is not observed at all from these two clouds if the interpretation of cloud - SN interaction is correct. If one accept this interpretation then very special conditions for high energy particle propagation should be assumed around the clouds. Besides, as follows from Sofue (1995) and Sawada et al. (1999) is not easy to determine the distances between these clouds and Sgr A*. In principle, the XMM-Newton data do not exclude also any stationary component of the 6.4 keV flux from these clouds below the derived upper limit.

5. Predicted Variations of the Sgr B2 eW in Near Future

Observations show that the flux of the 6.4 keV line emission from Sgr B2 is rapidly decreasing with time (see the left panel of figure 4). The question is whether we can find any evidence for a possible stationary component of Sgr B2. In figure 4 (right panel) we presented the expected variations of the Sgr B2 equivalent width when the flux generated by the primary X-rays, $F_{6.4}^{X}$, is dropping down to the level 20% (solid lines) and 10% (dashed lines) of the maximum value with the rate shown in the left panel of the figure. The calculations were done for protons with different spectral indexes γ and for electrons with $\gamma = -2.7$. One can see from the figure that in the case if these particles are electrons the value of eW decreases (almost independent of the electron spectral index, see figure 2). In the case of protons the situation is intricate: for soft proton spectra (negative γ) the value of eW should increase with time while for spectra with a positive spectral index it drops down. However, production of spectra with a positive γ in the Galaxy seems doubtful. In this figure we showed also the measured value of eW for the years 2005 and 2009 (see Nobukawa et al. 2011). Unfortunately, it is difficult to derive a time trend of the eW variations because of relatively large error boxes.

These calculations show that the equivalent width should in principle change if there is a component of Sgr B2 emission generated by subrelativistic particles. It follows from figure 4 that if the eW is decreasing with time than the origin of impact component is due to electrons. In the opposite case stationary component of 6.4 keV emission is produced by subrelativistic protons. If future observations do not find any time variation of the eW of the 6.4 keV line that will be a strong evidence in favour of their pure photoionization origin.

Recent Suzaku observations may find the iron line emission which is produced by subrelativistic particles (Fukuoka et al. 2009; Tsuru et al. 2010). For the clumps G 0.174−0.233 with $eW \simeq 950$ eV they concluded that the X-ray reflection nebula (XRN) scenario was favored. On the other hand, for the clump 6.4 keV G 0.162−0.217 with $eW \simeq 200$ eV they assumed that the emission from there was due to low energy cosmic-ray electron (LECRe). They found also that the eW of the 6.4 keV emission line detected in the X-ray faint region (non galactic molecular cloud region) is significantly lower than one expected in the XRN scenario but higher than that of the LECRe model. In this respect we notice that for the spectrum of protons in the interstellar medium of the GC with the spectral index $\gamma = 0.5$, as derived by Dogiel et al. (2009c), the eW of emission produced by protons is smaller than that of photoionization, that may explain these new Suzaku results (see Figs. 2 and 4 for the proton spectral index $\gamma = 0.5$).

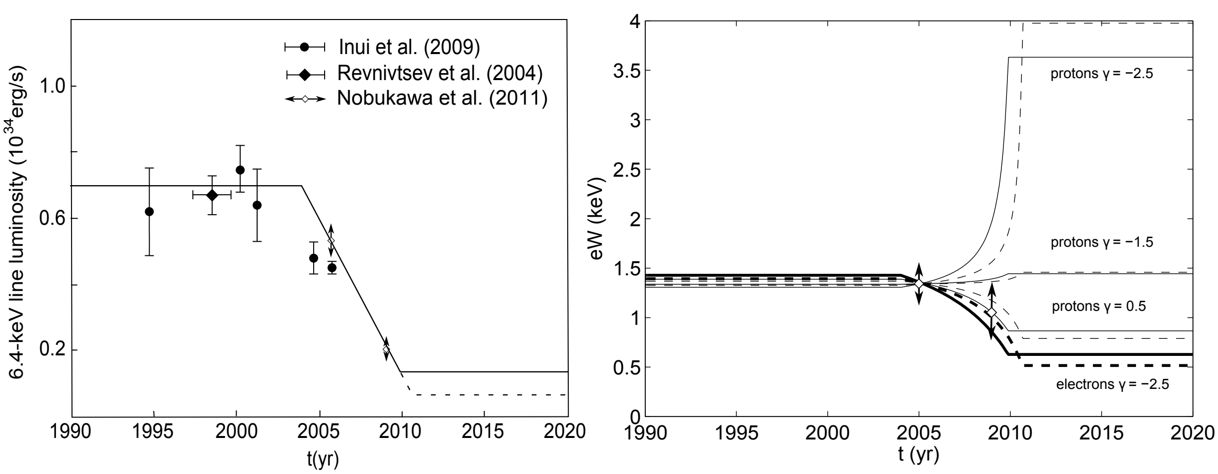

Fig. 4. *Left:* The evolution of the Fe Kα line luminosity and X-ray continuum as observed for Sgr B2. *Right:* The possible evolution of Fe Kα line equivalent width. Dashed lines correspond to $F^p_{6.4}/F^X_{6.4} = 0.1$, solid lines correspond to $F^p_{6.4}/F^X_{6.4} = 0.2$.

Future experiment can also distinguish the line origin from its width. If electrons and X-rays generate a very narrow 6.4 keV line with the width about 1 eV, the line produced by subrelativistic protons is rather broad, < 100 eV (see Dogiel et al. 1998). The estimated width of the Fe K line for the model presented in Dogiel et al. (2009a) is about 40 eV. If there is a noticeable proton component of the 6.4 keV flux from the clouds, the width of the line should

broaden with time.

Measurements of the line with present X-ray telescopes contains broadening which depends on photon statistics and calibration uncertainties. The energy resolution of CCD detectors at 6 keV is $\sim$130 eV which can be decreased after the de-convolution procedure (see Koyama et al. 2007b; Ebisawa et al. 2008). However, even with this procedure it is not easy to derive a true line width from observations, if it is about 40 eV. For more reliable results a detector with a high energy resolution of eV such as micro-calorimeter Astro-H/SXS is necessary.

6. Conclusion

We investigated parameters of the Kα line emission from the molecular clouds in the GC when it is excited by a flux of subrelativistic protons. These protons are generated by accretion onto the super-massive black hole. We concluded that:

- If these protons are generated by accretion processes they produce a quasi-stationary component of 6.4 keV line and continuum hard X-ray emission from molecular clouds in the GC because of their very long lifetime. In this situation two components of X-ray radiation should be observed: a time variable emission due to photoionization by primary X-ray photons emitted by Sgr A* and a quasi-stationary component generated by proton impact.
- Since the cross-sections of continuum and the iron line production are different for these two processes, we expect that they can be distinguished from the analysis of the equivalent width of the iron line and we can predict time variations of eW when the photoionization flux drops down after the passage of X-ray front injected by Sgr A*.
- Whether or not the stationary component excited by protons can be observed, depends on a distance of a cloud from Sgr A* and the coefficient of spacial diffusion in the GC medium. For the cloud G 0.11$-$0.11 which is relatively close to Sgr A* we expect to observe in a few years a stationary component of the 6.4 keV emission at the level $\lesssim$ 10% from its present value. For the cloud Sgr B2 the situation is more intricate. If the diffusion coefficient $D \gtrsim 10^{27}$ cm^{2}s^{-1} then the expected stationary flux should be about 10% of its level in 2000. In the opposite case the line intensity from Sgr B2 should drop down to zero because the protons do not reach the cloud.
- When the front of primary X-rays is passing through the clouds, the density of primary X-ray photons decreases and the relative contribution of the stationary iron line emission, if presents, into the total flux increases. Therefore, parameters of the emission from clouds changes with time. We expect that the spectrum of charged particles generating the stationary component can be derived from time variability of the line equivalent width.
- We showed that the equivalent width of the iron line excited by charged particles depends of their charge composition and spectral index γ. The equivalent width of Kα line generated

by electrons depends weakly on γ, and it varies from ~ 250 eV for soft spectra to ~ 500 eV for hard electron spectra. In the case of protons the width variations are significant reaching its maximum for very soft proton spectra.

- If future observations find any time variation of the eW of the 6.4 keV line, then in the case of decrease the impact line component is produced by electron, in the opposite case - by subrelativistic protons.

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